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Research Article

Thermal and emission analysis of spark ignition S.I engine using premium gasoline-ethanol-paraffin blends with different operating conditions

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ABSTRACT

The release of greenhouse gases and climate change are mostly caused by internal combustion engine emissions from combustion fossil fuels, especially those from gasoline engines. Ethanol can be been recognized as an alternative fuel to gasoline that may also help to reduce pollution. In this paper, the various ethanol-premium gasoline blends with partial additions of paraffin such as n-pentane, hexane, etc. were evaluated for engine performance, combustion, and emission characteristics. CO emissions are reduced by 12 and 15% respectively when hexane and pentane are blended with premium gasoline and ethanol blends. PG40E10P fuel blend had the lowest emissions amongst all fuel blend used in spark ignition engine. Hydrocarbons have been seen to diminish with the addition of hexane and pentane. Partial addition of paraffin assisted complete combustion of fuel therby reducing hydrocarbon emissions by 25%. PG60E10P fuel blend found to have least HC emission amongst all fuel blends. In addition, the cylinder pressure dropped when ethanol was added. The maximum braking thermal efficiency was determined to be PG10P as compared to PG . Paraffin blends helped in complete combustion of fuel and hence BTE improved slightly by 7% as compared with PG. A partial addition of paraffin to gasoline was shown to reduce CO emissions by 10% as compared with PG. The nitrogen oxides (NO_x) was found to decrease by 25% for PG40EP as compared to PG.

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INTRODUCTION

India is among the world's seventh-largest manufacture of ethanol and has tremendous potential. The increasing worldwide population has led to a rise in the need for energy, economy, power sector, and automobiles [1]. This has prompted the search for an alternative to fossil fuels that can meet the needs of people today. The amount of

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fossil fuels in the earth is directly correlated with human energy production needs. The interest in alternative fuels is greater than ever, especially given the situation of the global economy. It's imperative to keep in mind that replacement fuel ought to come from the renewable resources [2]. Bioethanol has offered a solution to the existing issue. Thus, its well knowledge that the best alternative fuel for spark-ignition (SI) engines is bio-ethanol. The world's most important alternative fuel ethanol was manufactured in the United States and key nations, with 158,000,000,000 gallons produced overall in 2019. In gallons, 8.6 billion. India has a huge amount of potential for manufacturing bioethanol as well as is currently the 05th largest manufacturer of ethanol worldwide [3]. The world's reliance on fossil fuels is growing daily, and so is the amount of fuel burned. On Earth, there are an increasing number of cars day by day, which is causing greenhouse gas emissions to rise. Various countries are attempting to control the quantity of emissions that originate from motor vehicles [4].

Due to the scarcity of unprocessed crude oil, the price of traditional engine fuel has skyrocketed in the previous couple decades. Additionally, traditional fuel is running out and won't last for more than a few years, so alternative fuels are required for conventional internal combustion engines. The most popular an alternate fuel to regular diesel is biodiesel, while bioethanol is used as a substitute for gasoline [5]. It is possible to produce bioethanol by fermenting sugar-containing crops such as sugarcane, rice straw, sugar beet, cereal grains, etc. Bioethanol of the first generation is produced via the fermentation of plants high in starch, such as sugarcane, wheat, corn, and sugarbeet, while in some nations such as the United States, Corn is utilized to produce bioethanol. Potatoes are utilized in European countries to produce bioethanol. Sugarcane is among the most preferred feedstock for producing ethanol in developing countries like Brazil and India. India stands as the fourth-largest sugarcane grower globally, after the United States, Brazil, the European Union, and China [6]. Second generation bioethanol, like first generation bioethanol, is produced using non-edible feedstock, such as lignocellulose materials and agricultural forest wastes. Compared to first generation bioethanol, these techniques call for more sophisticated methodology. Algae are used in third-generation ethanol to produce bioethanol. Algae are a better feedstock than other types because they can take carbon dioxide from the environment quickly and store large amounts of lipids and carbohydrates [7]. Additionally, growing algae takes less area than growing other plants that are used to produce biodiesel. Advanced methods are needed to produce bioethanol for both second and third generation. In addition, fourth generation bioethanol is a topic on which many researchers are focusing, which would employ creatures with genetic makeup like algae and yeast [8]. Furthermore, in most Asian countries, rice is the main food staple, and rice fields produce a substantial quantity of rice straw used as crop residue. In addition to putting the environment in peril by releasing large volumes of greenhouse gases (GHG), burning crops in the open and the irresponsible using rice straw also cost farmers a very profitable by-product [9]. Utilizing rice straw to produce bioethanol has the potential to boost profits while also being environmentally sustainable. It would also provide India with a sustainable energy solution to meet its ever growing energy needs. However, it becomes increasingly important to research the viability of producing bioethanol from straw made of rice and how it might be logical in India's existing agricultural setting. Despite the carbon neutrality of the bioethanol produced from rice straw, concerns have been raised regarding the entire process, including rice logistics, pre-treatment, and agriculture [10]. The release of greenhouse gases from each phase of the life cycle of engine are used to assess the effects on the environment [11]. The article offers a prediction regarding the current state and possible futures of the nation's ethanol blending business. The biofuel program has been bolstered by government initiatives that enhance energy security by substituting some of the limited fossil sources and reducing environmental the damage caused by exhaust emissions and global warming. In India, spark ignition engines currently run on E10 blended fuel, which is 90% gasoline and 10% ethanol. In the following years, E20 blended fuel, which is 90% gasoline and 20% ethanol, will be used without requiring engine modifications [12]. Flexi-fuel vehicles are already in use in numerous nations, including the United States, Brazil, and others. By partially substituting the shortage of fossil fuels and reducing the environmental damage from exhaust emissions and heat, government rules have aided the biofuel program in the pursuit of energy security [13]. Biofuels are the main fuel that has been found to be a more significant substitute for gasoline. Furthermore, biofuel produces fewer greenhouse gases, such carbon dioxide [14]. Whether it is crude oil or biofuel, how much carbon is in the fuel burns and releases carbonic acid gas into the atmosphere. The impact of gasoline-ethanol mixtures on emissions and engine efficiency have been the subject of several studies. Biofuels have several advantages, including being very environmentally friendly, utilizing common sources of biomass, generating carbon dioxide produced during burning, being perishable, and adding value to property [15].

The Production of Ethanol in Indıa and Across the Globe

On June 8, 2018, the government released the National Policy 2018 on Biofuels notification. It plans to add 20% ethanol to fuel by 2030. The Ethanol Blended Petrol (EBP) program is managed by the government through the Oil Marketing Companies (OMC). OMC offers up to 10% ethanol-blended gasoline for sale as part of this program. Apart from sugar and honey, On 10th December, 2014, the government decided to increase the amount of ethanol available by using petrochemical processes to produce ethanol from non-food components including cellulose and apple cellulose. Furthermore, the government had given its approval on the processing of damaged grains into ethanol. The ethanol supply volume was 149.54 million litres of gasoline and ethanol in the preceding fiscal year, with the highest average mixing ratio in EBP history of 4.19% [3] The software is having 114 applications totalling $613.9 million, or an estimated two hundred billion litres of ethanol production capacity each year, as part of the Ministry of Food and Public Distribution's initiative to provide sugar mills with more funding to enhance and extend their ethanol production capabilities. The Brazilian national policy keeps the fuel blend standard of 18–27.5% ethanol starting in 2015 [16]. It is currently 27 percent ethanol in gasoline (E27 mixed gasoline) used in Brazil for motorcycles and other two-wheeler engines. In compliance with the Clean Air Act, the EPA is required to establish the volume requirements for the Renewable Fuel Standards (RFS) every year in the United States. The EPA adjusts the minimum volume needed annually to account for changes in fuel availability. For vehicles that use flex fuel, they use mixed fuels like E30 or E85 under the Renewable Fuel Standard (RFS) program. The European Union wants 10% of the transportation in each member state fuel to come from renewable sources, such as biofuels, by 2020 [17]. In September 2017, the Chinese government released legislation requiring all of China to utilize ethanol as fuel, with a 10% goal ethanol blending. By 2036, biofuel-derived alternative and renewable energy is expected to account for 25% of fuel energy use in Thailand, up from 7% in 2015. This is according to the country's Alternative Energy Development Plan (ADEP) [18].

Advantages of Blending gasoline with ethanol results in increased fuel efficiency, enrichment of oxygen concentration in the fuel and flame speed. Since ethanol possesses a calorific value that is around two thirds that of gasoline, the ethanol-petrol mixture's calorific value will drop with an increase in the ethanol blend [19]. Therefore, it takes a higher fuel combination to produce the same level of power as pure fuel. The engine may run at a greater compression ratio when running on ethanol since it has a higher octane number than pure gasoline. Increasing the compression ratio of a SI engine can increase its thermal efficiency. Furthermore, ethanol has a higher heat of vaporization than pure gasoline because of the charge cooling effect, which contributes to the increased volumetric efficiency of SI engines [20].

Literature Review

Sakthivel et al. [21] used a chassis dynamometer to investigate the combustion, how they perform, as well as emissions characteristics for a two-wheeled vehicle using an alcohol-based blend of petrol and petrol comprising 30% ethanol. E0 as well as E30 mixtures were employed. They concluded that even though the carbon monoxide and hydrocarbon emissions of the fuel paired using E30 had been lowered by 75% and 66%, consequently, the emissions of nitrogen oxides (NOx) were almost 2.5 times those of E0. Sakai et al. [22] investigated how ethanol affected particle emissions from engines powered by gasoline. Various ethanol-gasoline mixtures have been combusted in spark-ignited directly injected (SIDI) engines to better understand the formation of particulate matter. Despite large variances in fuel quality, the results of this study reveal that increasing the ethanol concentration leads in an overall decrease in raw engine particulates. Furthermore, engine operation history has been demonstrated to influence particulate matter results. Sakthivel et al.[23] conducted investigations into the market for fuel based on ethanol in India and its application in the transportation sector. They said that in order to increase the availability of ethanol for mixing, these various raw materials might be utilized and that ethanol transformation processes would be necessary. Ethanol blends reduce gasoline sulphur, aromatic compounds, olefins, as well as benzene emissions, as particulate, hydrocarbons, and carbon monoxide emissions. Two-wheelers consume around 61.4% of the fuel generated, while four-wheelers consume 34.3%. This indicates that about two thirds of gasoline is used by two-wheelers. This suggests that a concentrated effort to reduce particulate matter and enhanced fuel economy are both necessary. A study on how ethanol mixtures affect gasoline engine performance was carried out by Chansauria et al. [19]. The effects of various blends of ethanol on ethanol characteristics, production methods, as well as engine performance were examined and clarified in this study. After seeing that BSFC increases when ethanol level rises, Thakur et al. [11] reached this conclusion. BSFC increased by 5.17 percent, 10%, 20%, 37%, and 56%, respectively, when E20, E25, E30, E75, and E100 were employed. Modifications to the compression ratio (C.R) and engine speed also had an effect on the performance characteristics of the gasoline engine. The utilization of E50 as well as E85 rose by 20.3%, 45.6%, 16.15%, and 36.4% in 10:1 and 11:1 CRs, respectively, with this finding. Researchers Akansu et al. [24] carried out experimental studies on the combustion of gasoline and ethanol in a SI engine. Engine performance has increased and emissions have decreased with hydrogen. The findings demonstrated that incorporating hydrogen into a gasoline-ethanol mixture increased burning speed, enhanced combustion efficiency, broadened the range of flammability, and decreased pollutants. When 20 percent gasoline was added to ethanol, NO_x emissions were lowered by as much as 50%. The effects of the mixing of ethanol on particles generated by gasoline engines Sakai and colleagues [25] investigated burning. The production of particles by the combustion engine was seen as different ethanol-gasoline combinations burned. Changes in the concentration of ethanol and the corresponding ratio could be studied because the engine was operated at a constant load and phase. The results of the investigation illustrates that regular addition of ethanol precisely matches the reduction in particulate matter (P.M) streaming from engine exhaust. In a wall-guided, multi-cylinder, turbocharged optical engine using GDI technology, Catapano et al. [26] examined the combustion and mixing properties of gasoline-ethanol combination. Using various combinations of ethanol and gasoline, investigations were conducted on the behavior of an optically visible 4-stroke, 4-cylinder engine with direct gasoline injection under partial load and speed scenarios. Engine efficiency was improved by adding ethanol to gasoline, as evidenced by the quoted mean effective pressure and emissions figures.

Gowda et. al [27] have done Comparative analysis of carbon particle emissions from exhaust of an IC engine using HSD and blends of HSD and Honge/Jatropha biodiesel. In order to quantify the amounts and sizes of carbon particulate matter emissions in engine exhaust, experiments were conducted on biodiesel blends with diesel. The results are summarized in this publication. To run a single-cylinder, four-stroke diesel engine, blends of two esterified oils—Hange (Pongamia Pinnata) and Jatropha—with petrodiesel were utilized. The blend ratios of 5%, 10%, 15%, and 20% were employed. For five minutes, the carbon particles from the exhaust were gathered on INDICA filter paper. The conventional method was used to determine the carbon content, and microscopic analysis was used to determine the size of the particles. For the mixes of Jatropha and Honge, independent ANOVA analyses of the data were conducted. The experiment's outcomes are understandable and fascinating. In comparison to diesel, both the Honge and Jatropha mixes raise the amount of carbon particles in engine exhaust. As the engine's load increases, so do the carbon particles. In the case of Jatropha blends, an increase in blend ratio typically results in a rise in carbon in the exhaust. When using Honge blends, the behavior is different. mix H10 has the most carbon in its exhaust at high loads, while mix H5 has the most carbon in its exhaust at low loads.

Karagöz [28] perfomred emıssıons and performance characterıstıcs of an S.I. engıne wıth bıogas fuel at dıfferent CO_2 ratıos. Using biogas fuel in various ratios, a single cylinder, four stroke SI engine was run at stoichiometric conditions at a constant engine speed of 2800 rpm. Methane (CH4) and CO2 were employed as biogas fuel in engine experiments. The outcomes of tests conducted with gasoline alone were contrasted with those obtained using biogas fuel at various CO2 ratios (10%, 20%, 30%, and 40% by volume). While specific CO emissions were found to drop and THC emissions to slightly increase with increasing CO_2 ratio, the adoption of a three-way catalytic converter is anticipated to prevent the increase in THC emissions. Although using biogas results in higher NOx emissions than using gasoline, these emissions are greatly mitigated by the fuel's lower O2 availability, increased CO2 rate, and CO2's heat-carrying capability. However, it is anticipated that using biogas with a high CO2 ratio in SI engines will reduce NOx emissions due to the high cost of the purification process and after-treatment equipment.

Karagöz et. al [29] experimentally investigated effect of dıfferent levels of hydrogen and liquified petroleum gas (LPG) addition on the performance and emission of a C.I.engine. The impact of LPG + H2 emissions on CO, THC, NOx, and smoke emissions is examined at four different energy contents at full load and the same torque (70 Nm) at a constant engine speed of 1200 rpm. The data showed that CO and THC emissions, as well as brake thermal efficiency, had somewhat increased. On the other hand, there has been a noticeable improvement in smoke and NOx emissions. The findings demonstrate that NOx and smoke emissions from diesel engines can be greatly decreased by employing LPG + H2 in combination with older, less expensive after-treatment equipment. Additionally, a significant improvement can be made by adding a tiny amount of hydrogen (20% of the entire gas combination) and LPG.

When testing engines, Patil et al. [30] carried out an investigation using an experiment to assess the efficacy of alternative fuels. Using a chromatographic test, they also ascertained the composition of premium gasoline. The aromatics compound mass percentage was discovered to be 98.41% according to the PIONA compound mass comparison, compared to 82.8% in earlier research studies. Isoparaffin was absent, and the paraffin mass percentage share was 0.656, or 9.5%, in the previous researchers' study. Based on these investigations, the decision was made to blend 10% of alkanes (n-pentane, hexane, etc.) with premium gasoline for the purpose of study the fuel's performance, combustion, as well as emission characteristics at 20%, 40%, and 60% ethanol blends. Solubility criteria are used because it is assumed that analogous compounds will have an affinity for one another and will be more likely to absorb or dissolve in one another. The three main benefits of ethanol bending are a higher octane number, oxygen enhanced fuel, and a more rapid flame result in full combustion fuel [31].

To acquire true auto ignition properties in gasoline, a technique called gas chromatography with paired high resolution mass spectrometry (GC-HRMS) must be utilized to maintain a balance between aromatics and branching paraffin. Employing high-resolution mass spectrometry gas chromatography (GCHRMS), Patil et al. [2] evaluated commercially available gasoline at the Indian Institute of Technology (IIT) Bombay's Sophisticated Analytical Instrument Facility (SAIF).

The detailed composition of premium gasoline is as follows:

McCormick experimentally determined that gasoline contains 10% paraffin in its chemical composition [32]. Furthermore, it is necessary to study impact of combustion, performance and emission characteristics of internal combustion engine with different operating conditions. The main objective of this research is to analyse and relate the thermal performance, combustion, and emission characteristics of premium gasoline-ethanol blends with partial additions of paraffin i.e.10% (by volume) pentane and hexane under various operating conditions of spark ignition engine. Also, the effect of partial addition of paraffin in premium gasoline-ethanol blend is under different operating conditions.

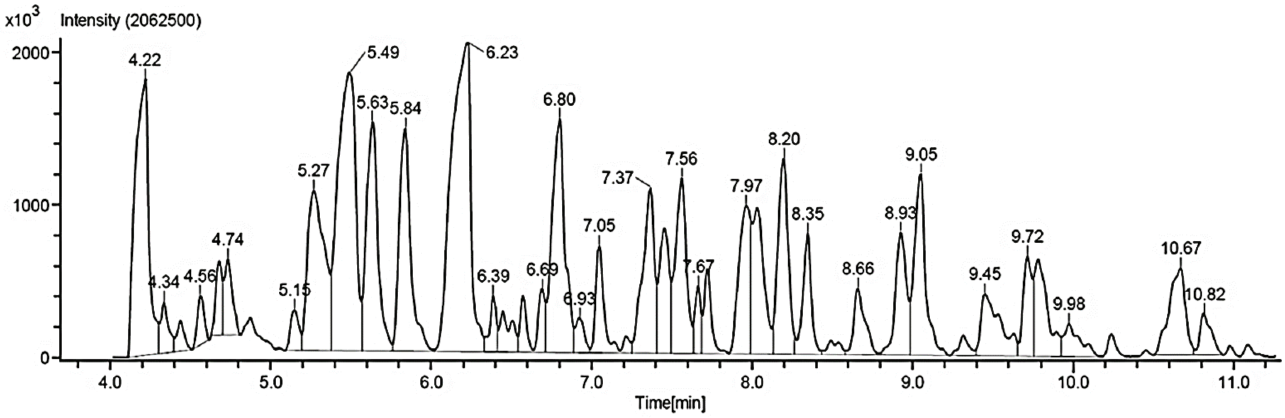

Figure 1. Premium gasoline intensity-time distribution chromatograph [17] copyright from Fuel 5600240981225.

Table 1. Composition of Premium gasoline (Patil.;2023)

Name of compound	Mass percentage
Aromatics hydrocarbon compound	
Benzen, 1,2,3-Trimethyl	21.66%
m-ethyl, tolune	9.26%,
O-Xylene	7.04%,
O-ethyl, tolune	4.80%,
Benzen, 1,2,4,5-tetramethyl	4.14%,
2-ethyl-p-xylene	3.69%,
2-ethyl-p-xylene	3.62%,
O-propyl-toluene	3.51%,
Indan, 5-ethyl-m-xylene	3.30%,
5-methyl	2.25%,
5-ethyl-m-xylene	2.27%,
Benzen, 1,2,3,4-tetramethyl	2.52%
Esters	3.74%
Hydrocarbon	8.11%
Diverse functional group	10.08%
Ketone	1.38%
Nitrogen containing group	0.86%
Other compounds	6.02%

Methodology and Experimentation

Experiments were conducted on blended fuels containing ethanol and petroleum using a single-cylinder, four-stroke gasoline engine with varying spark timing. To measure the load on the engine, the water-cooled loading components of an eddy current dynamometer were included in the attachment. For the purpose of logging engine cylinder pressure and crank angle, the engine was additionally outfitted with appropriate equipment such as a crank angle encoder, pressure transmitter, and so on. A fuel flow transmitter and an air flow transmitter were installed with the engine test setup to measure fuel and air flow rates. To measure water flow, two water rotameters were employed. Variations in load were recorded using digital load indicators.

A four-stroke, single-cylinder spark-ignition engine was linked to a Testo-350 flue gas analyzer, a Lutron SL-4001 digital sound level meter, and computerized Enginesoft LV result analysis software. Prior to starting the trials, a preliminary check of the test setup was performed, looking for fuel leaks, tightened nuts, and other issues. After every test, the lubricating oil was reviewed as well to make sure it was properly lubricated. Prior to the testing, the fuel lines were cleared of air. The voltmeter, load indication (dynamometer loading unit), piezo-powering unit, and other devices all had their power supplies inspected. Water flow rates of 100 LPH and 250 LPH, respectively, were maintained for the calorimeter and engine cooling jacket. Using a centrifugal water pump, a continuous cooling water supply was given to the calorimeter, eddy current dynamometer, as well as engine jacket. Using a digital load indicator, the engine load was noted. Engine performance and combustion characteristics were recorded using the Engine-soft LV result analysis program, which is built in LabVIEW. Engine exhaust emissions, including CO, CO_2, and NO_x, were measured using a Testo-350 flue gas analyzer. The environmental temperature was 300 K and the trials were conducted at atmospheric pressure. It was believed that the experimentation took place in the same ambient conditions.

The characteristics of a premium gasoline (PG) fuel were compared with the performance (brake thermal efficiency; BTE), brake-specific fuel consumption (BSFC); emissions (CO, HC, and NO_x); and combustion (cylinder pressure; mean gas temperature (MGT),) of gasoline-ethanol-paraffin fuel blends.

The engine's emissions were measured using the gas analyser. There were five gas analysers in service. The flame ionization detector (FID) method was employed to assess the hydrocarbon (HC) emissions. We measured the carbon oxides (CO and CO2) using non-dispersive

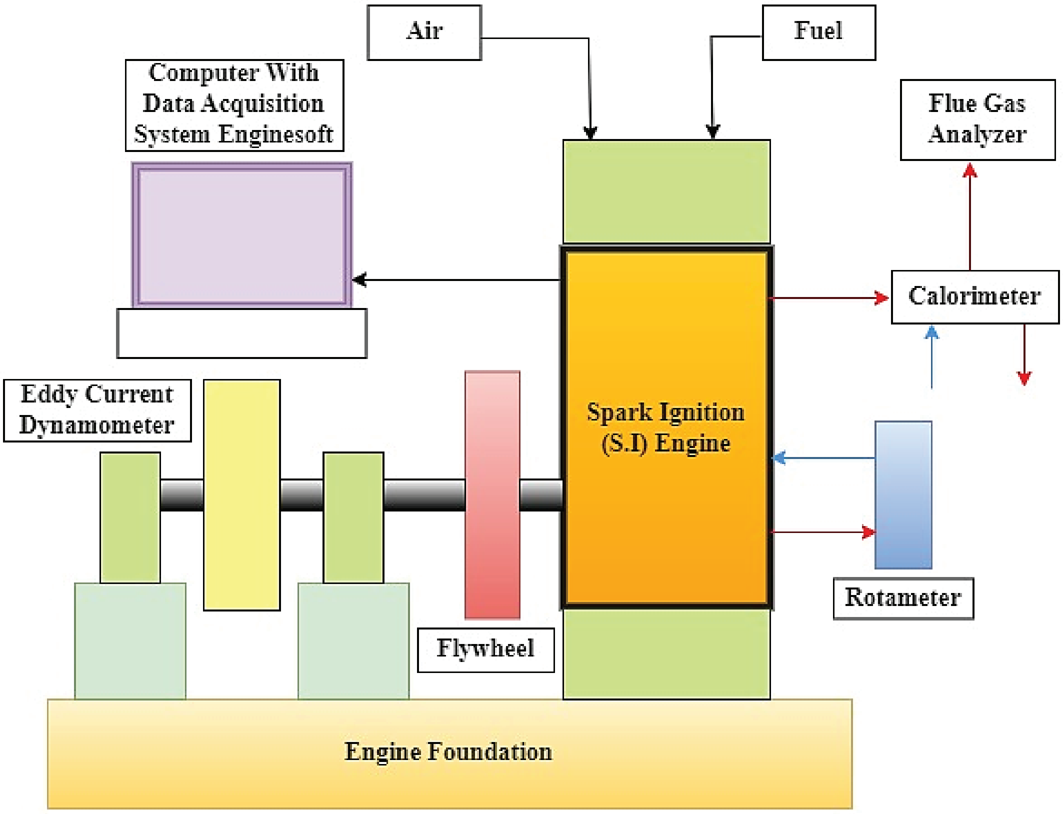

Figure 2. The schematic diagram of engine set-up.

Figure 3. Experimental set-up of four stroke single cylinder engine.

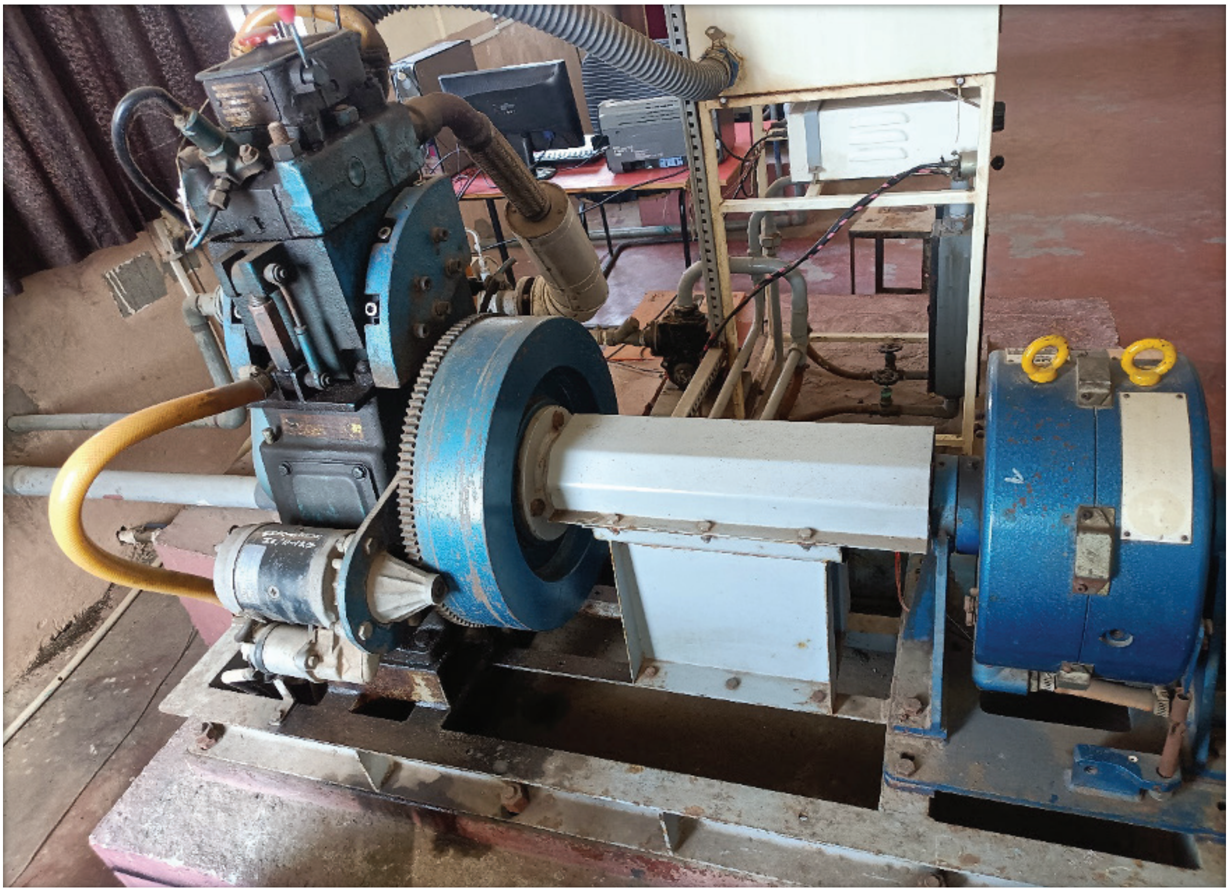

Figure 4. Experimental set-up.

Figure 5. Mechanical blender.

infrared (NDIR) technology. The pressure transmitter measures the cylinder pressure with an accuracy of ±0.25 bar and an uncertainty of ±0.25%. A crank angle encoder was used to measure the crankshaft's crank angle with an accuracy of ±1° and ±1% uncertainty. The root mean square (RMS) methodology was utilized in experimental research to assess the uncertainties using Kline and McClintock's method. Kline and McClintock's equation is as follows:

$$\omega_R = \sqrt{(\frac{\partial R}{\partial x_1}\omega_1)^2 + (\frac{\partial R}{\partial x_2}\omega_2)^2 + (\frac{\partial R}{\partial x_3}\omega_3)^2 + \cdots + (\frac{\partial R}{\partial x_n}\omega_n)^2} \quad (1)$$

where,

ω_R= Analysis of total system errors.

$x_1, x_2, x_3, \ldots, x_n$ = R function independent variables

$\omega_1, \omega_2, \omega_3, \ldots, \omega_n$= independent variable error

Reportedly, there is a 5 percent tolerable level of uncertainty. The RMS value is confirmed to be below the allowable limit for the current investigation.

A Mechanical blender were used to prepare fuel blends as shown in Figure 5. Twelve blends were prepared usig mechanical blender in a laboratory.

RESULTS AND DISCUSSION

As gasoline contains already 10% paraffin in it. Therefore, thermal and emission analysis of spark ignition engine were investigated with addition 10% paraffin in premium gasoline. Ethanol is oxygenated fuel which helps in combustion process. Twelve different blends were prepared and thermal and emission analysis were done.

1. **Effect on Brake Thermal Efficiency (B.T.E) using premium gasoline-ethanol-paraffin blends:**

Figure. 6 shows the brake thermal efficiency for several premium gasoline paraffin blends. We evaluated twelve different mixtures. All mixes braking thermal efficiency was compared to that of premium gasoline (PG). It was discovered that when ethanol blending % increases, brake thermal efficiency drops. However, the combination of n-pentane and hexane results in a modest increase in brake thermal efficiency. Out of all fuel blends used, PG10P fuel blend had the maximum efficiency. Additionally, it was found that PG20H and

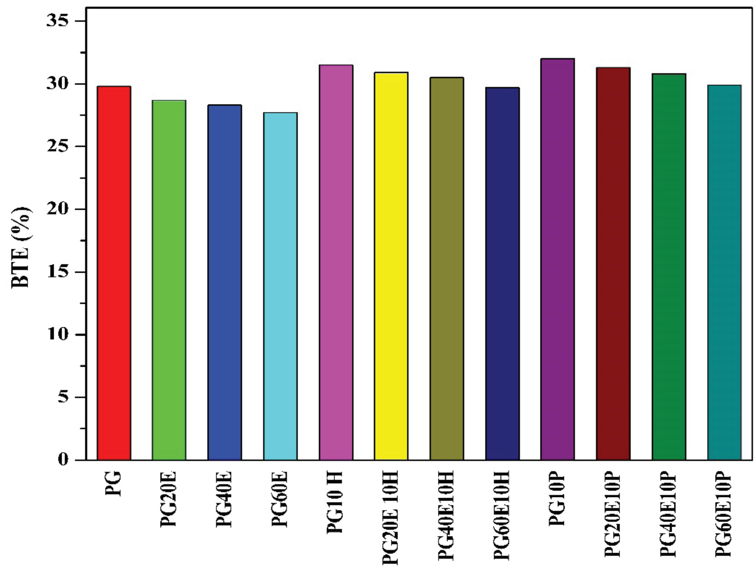

Figure 6. Effect on brake thermal efficiency (BTE) of spark ignition (S.I) engine using gasoline-ethanol-paraffin blends.

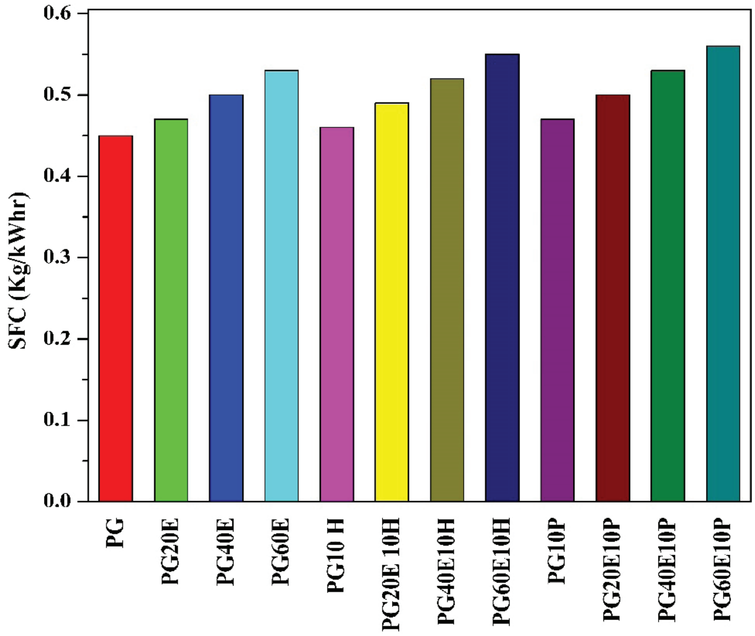

Figure 7. Effect on specific fuel consumption (SFC) of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends.

PG20P fuel blend and paraffin had a greater effect on the engine's brake thermal efficiency. The maximum brake thermal efficiency was determined to be PG10P. Paraffin blends helped in complete combustion of fuel and hence BTE improved slightly by 7% as compared to PG. BTE rises as the pilot gasoline quantity grows up to a 60% load, but as pilot gasoline supply increases at greater loads, BTE falls. When the engine accelerates, the brake thermal efficiency first rises in the vicinity of the optimal state before falling.

2. **Effect on Specific Fuel Consumption (SFC) of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends:**
   The quantity of fuel used by an engine for each unit of work completed is known as its specific fuel consumption. A decrease in calorific value results in an increase in fuel consumption and, consequently, in SFC. As the ethanol share in fuel blend increases in premium gasoline up to 60% by volume, the specific fuel consumption increases gradually. It was found that SFC increases by 15% with addition of ethanol and paraffin's in premium gasoline. From PG to PG60E10P, PG20E fuel blend showed optimum value of specific fuel consumption as there were no much difference in SFC values of PG60E10H and PG60E10P as shown in Figure. 7
3. **Effect on Cylinder Pressure of spark ignition (S.I) engine using premium gasoline-ethanol-Paraffin blends:**
   The fluctuation of cylinder pressure with relation to crank angle is depicted in Figure 8. The cylinder pressure was higher for PG20P and PG20H, respectively. Premium gasoline (PG) has a higher heat of combustion and H/C ratio, as well as superior antiknock behaviour, than other selected fuels due to its higher research octane number (RON = 95). Peak cylinder pressures were recorded for both pure gasoline (PG) and partial alkane additions (PG10P & PG10H). Additionally, cylinder pressure somewhat dropped with 20% ethanol blend.
4. **Effect on emission characteristics of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends:**
   a. **Effect on emission characteristics of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends:**
      The effect on hydrocarbon (HC) emissions are as shown in Figure 9. It was found that as the proportion of ethanol increased in premium gasoline from PG to PG60E, hydrocarbon emissions gradually decreased.

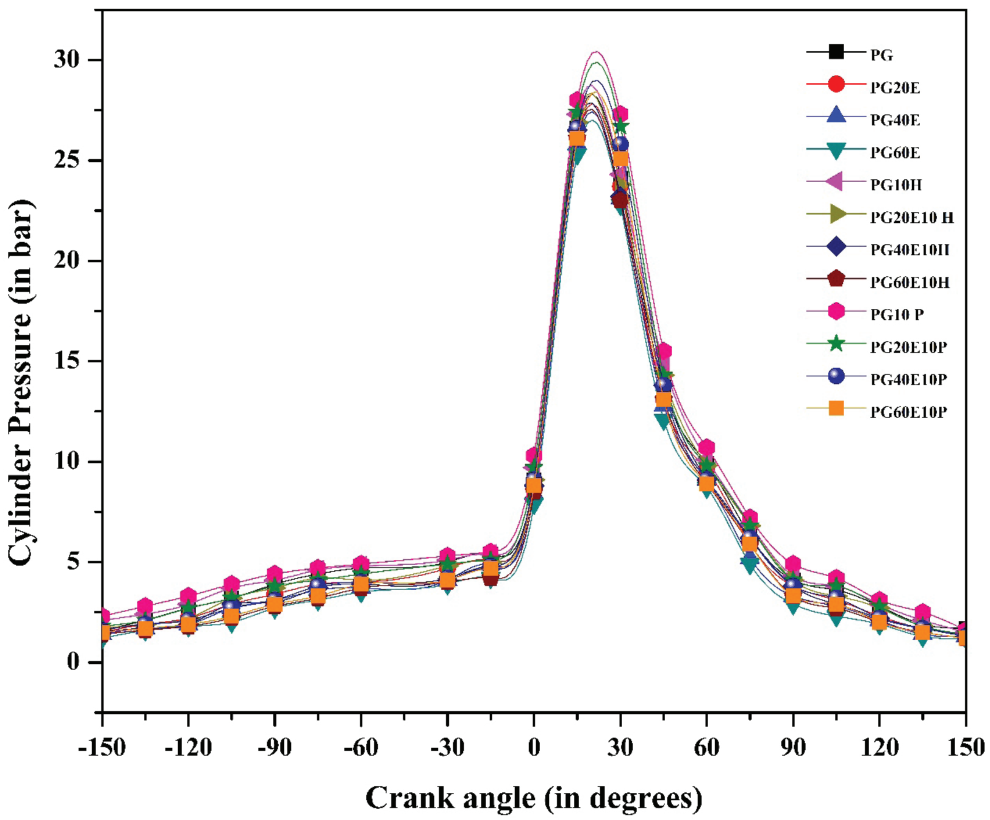

Figure 8. Effect on cylinder pressure of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin.

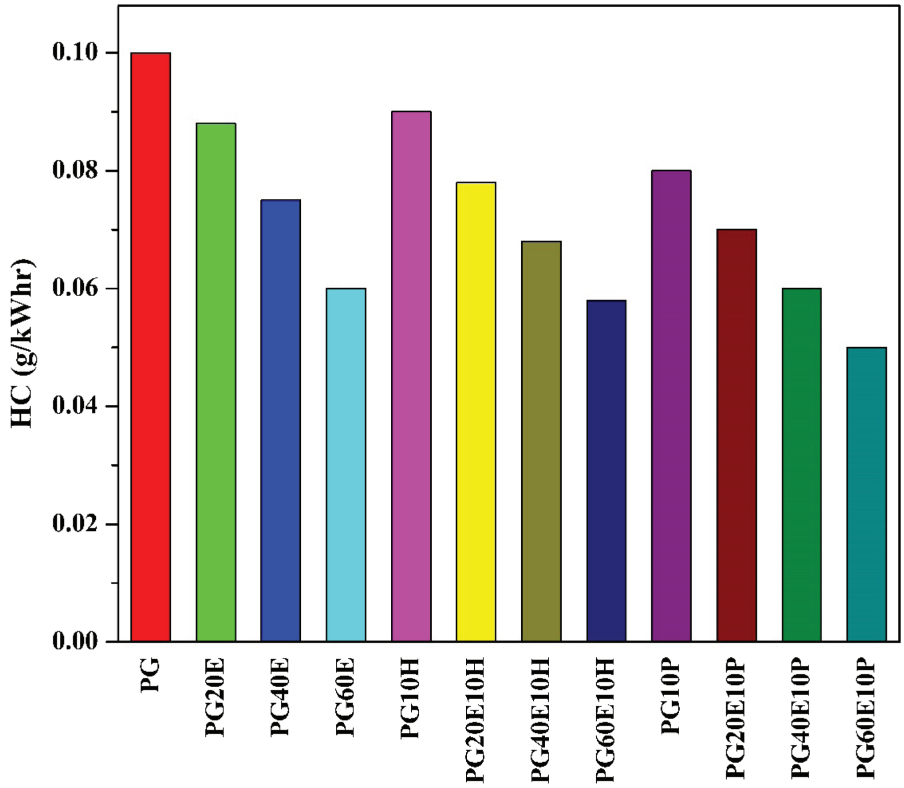

Figure 9. Effect on hydrocarbon (HC) emissions of spark ignition (S.I) engine using premium gasoline-ethanol-parafin.

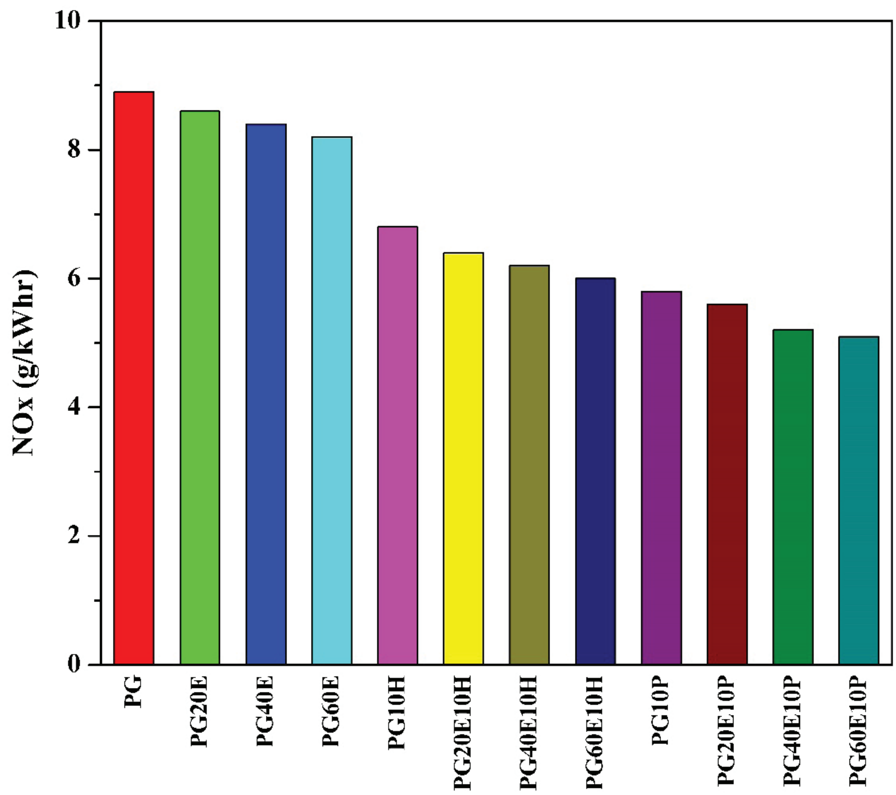

Figure. 10: Effect on oxides of nitrogen (NOx) emissions of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends.

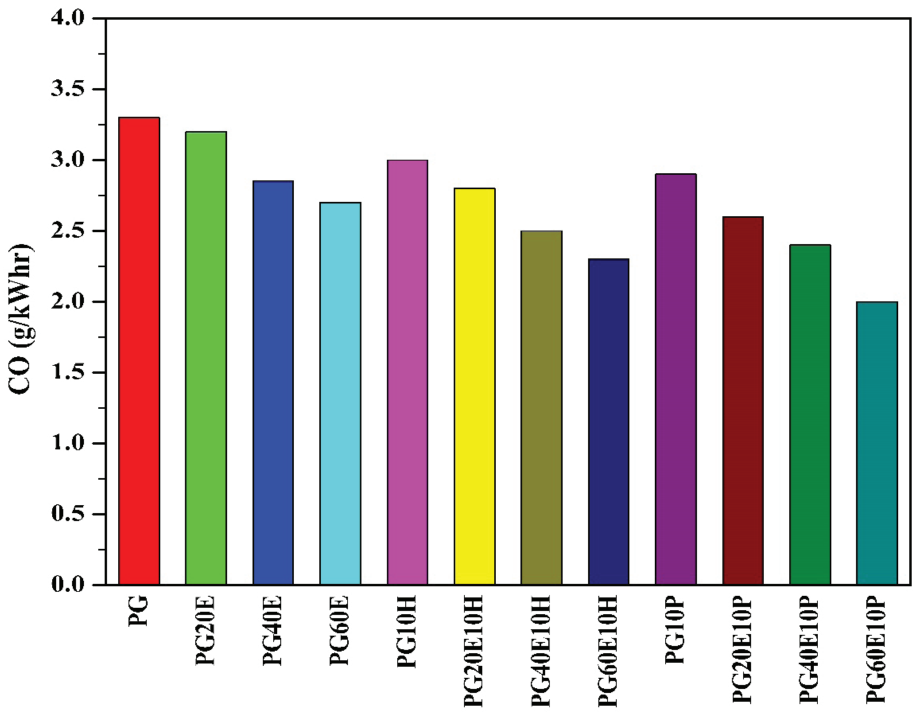

Figure.11: Effect on carbon monoxide (CO) emissions of spark ignition (S.I) engine using premium gasoline-ethanol-paraffin blends

With partial addition of parafin (10% by Volume) in premium gasoline- ethanol blends further showed prominent results on the features of spark ignition engines' emissions. The n-Pentane showed better results than Hexane. As ethanol is enriched in oxygen content, it helped to reduce hydrocarbon emissions during combustion process. The hydrocarbon emission were reduced by 25% with addition of paraffin in premium gasoline-ethanol blends. There was combined effect of ethanol and paraffin on the hydrocarbon emissions of spark ignition (S.I) engine.

b. **Effect on oxides of Nitrogen (NOx) emissions characteristics of spark ignition (S.I) engine using premium gasoline-ethanol with partial addition of paraffin**

The oxides of Nitrogen (NO_x) generally formed at higher temperature during combustion of fuels. As the ethanol is oxygenated fuel, it helps in complete combustion of fuel blends. Hence, NO_x emissions decreases for all the blends at all spark timing before TDC. It was observed that the oxides of Nitrogen (NOx) decreased gradually from PG to PG60E10P. The minimum NO_x found at PG60E10P fuel blend. With partial addition of hexane and n-pentane in premium gasoline-ethanol blends, further the reduction in oxides of nitrogen took place by 25%. As compared to hexane, n-pentane showed prominent results. The effect on NO_x emissions of spark ignition engines is shown in Figure.10

c. **Effect on Carbon Monoxide (CO) emissions characteristics of spark ignition (S.I) engine using premium gasoline-ethanol with partial addition of paraffin**

The carbon monoxide generally produced due to incomplete combustion of fuels. It was found that CO emissions decreased PG to PG60E for all blends. The minimum CO emissions were observed at 24°b TDC for both paraffin's added in fuel blends as shown in Figure. 11. Out of two paraffin's partially blended in premium gasoline-ethanol blends, n-Pentane had better results than hexane comparatively.

CONCLUSION

The thermal and emission analysis of single cylinder, spark ignition (S.I) engine powered by premium gasoline-ethanol-paraffin blends are reported in the present investigations. It is found that with partial addition of paraffin in premium gasoline-ethanol blends, BTE of blends PG to PG60E gradually decreased up to 10%. PG20E10P fuel blend had better results among PG20E, PG40E and PG60E. There is positive impact on emission characteristics of engine.

➢ It were noted that BTE of fuel blends decreased with addition of ethanol, but BTE of PG10H, PG10P, PG20H, PG20P slightly increased. This positive impact were observed by addition of partial paraffin's in premium gasoline-ethanol blends.

- The fluctuation in cylinder pressure were observed. The cylinder pressure was higher for PG20P and PG20H, respectively.
- Engine emissions viz. hydrocarbon (HC) emissions, oxides of Nitrogen (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO_2) were decreased as ethanol percentage is increased. PG20E fuel blend showed better results. The engine emissions were also investigated with spark advancement and spark retardment. CO emissions are reduced by 12 and 15% respectively when hexane and pentane are blended with premium gasoline and ethanol blends. PG60E10P (Premium gasoline + 60% Ethanol + 10% pentane) have the lowest emissions among all fuel blends used in spark ignition engine
- Therefore, PG20E appears to be more promising than other fuel blends used and PG fuel examined in terms of BTE of spark ignition engine based on thermal and emissions characteristics.

The advantages of the present research is to improve thermal efficiency of internal combustion engine and to reduce emissions releasing from internal combustion engine.

FUTURE SCOPE

Researchers studying engines will find benefit in the current investigation's findings as they seek to forecast favourable engine operating conditions through minimum emissions and optimistic performance of engine. Also, in addition to paraffin, hydrogen can be injected for enrichment of properties of fuel blends in the current research. The machine learning approach can also be used to predict the performance, combustion and emission characteristics of spark ignition engine with different operating conditions.

VALIDATION

Each trial of present experimental investigations were conducted five times and then all results were validated. All the instruments used in this investigations were calibrated and the error analysis were done by using Kline and McClintock's method. There were approximately five percentage uncertainty in the measuring instruments.

NOMENCLATURE

Premium gasoline – PG
Premium gasoline + 20% Ethanol – PG20E
Premium gasoline + 40% Ethanol – PG40E
Premium gasoline + 60% Ethanol – PG60E
Premium gasoline + 10% Hexane – PG10H
Premium gasoline + 20% Ethanol + 10% Hexane – PG20E10H
Premium gasoline + 40% Ethanol + 10% Hexane – PG40E10H
Premium gasoline + 60% Ethanol + 10% Hexane – PG60E10H
Premium gasoline + 10% pentane – PG10P
Premium gasoline + 20% Ethanol + 10% pentane – PG20E10P
Premium gasoline + 40% Ethanol + 10% pentane – PG40E10P
Premium gasoline + 60% Ethanol + 10% pentane – PG60E10P
BTE – Brake Thermal Efficiency
CO – Carbon monoxide
NOx – Nitrogen Oxides
HC – Hydrocarbons
SFC – Specific Fuel Consumption
bTDC – before Top Dead Center
LPH - liters per hour

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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